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THE CORRELATION OF SODIUM AND POTASSIUM METABOLISM WITH THE LEVEL OF ENERGY CONSUMPTION IN MAN DURING ADAPTATION TO HEAT

B. G. Afanas'yev and V. A. Zhestovskiy

Translation of "O vzaimosvyazi obmena natriya i kaliya s urovnem energotrat v protsesse adaptatsii cheloveka k teplu," Gigiena i Sanitariya, Vol. 36, No. 6, 1971, pp. 32-37

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16. Abstract

The sodium and potassium metabolism was studied in a thermal chamber at 35° and 80% relative humidity in 8 men for a period of 6 days. The control group (3 subjects) were otuside of the chamber at a comfortable ambient temperature. The intracellular sodium and potassium metabolism were assessed based on their content in the erythrocytes. The finding was that during adaptation to heat, a considerable amount of sodium was excreted by the body in the sweat and urine (about 1/3 of the sodium content of the human body) as compared with its intake and the amount of potassium retained in the body. Changes in the concentration of sodium and potassium may serve as indices of the state of adaptation processes during constant exposure to heat.

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THE CORRELATION OF SODIUM AND POTASSIUM METABOLISM WITH THE LEVEL OF ENERGY CONSUMPTION IN MAN DURING ADAPTATION TO HEAT

B. G. Afanas'yev and V. A. Zhestovskiy
Department of Naval Hygiene of the S. M. Kirov Military Medicine Academy, Leningrad

Changes in the concentration of sodium and potassium ions in the blood resulting from the action of thermal factors on the body have lately been the object of much study (Ya. S. Kuno et al.). One reason for this is that sodium and potassium ions have marked effects on metabolic processes and thus play an active role in the body's adaptive responses. In healthy persons kept on a sodium chloride-free diet for 10 days, no metabolic changes were found. However, when this diet was combined with measures producing additional NaCl losses (diaphoresis and diuresis), a significant fall of the metabolism was noted. /32*

Ogata found that inhabitants of Northern Manchuria typically consume 40 g NaCl and more per day during the winter months with no noticeable physiologic disturbances. Ogata and his coworkers conducted experiments to determine the effects of increased NaCl consumption during a severe winter period. According to their findings, the daily consumption of 50-60 g NaCl for several days led to a gradual rise of the basal metabolism and an improvement of appetite and general well-being. A significant increase in cold resistance was also observed. On the other hand, studies by A. Yu. Yunusov on foundry workers in Tashkent who lived and worked under conditions of a high air temperature indicate a maximum safe dose of 16 g NaCl per day. Consolazio reports that a salt consumption of more than 15 g per day impedes acclimatization to high

* Numbers in the margin indicate pagination in the foreign text.

temperatures (Du Bois; Henane). All these studies point to a direct connection between basal metabolism and the consumption of NaCl, although no data are given on the pathways of sodium transport in the body, and potassium metabolism is ignored.

A number of authors (G. A. Lushnikova; A. Yu. Yunusov et al.; Frada and Mentasana; Mitkova and Raitcheva; Michelet et al.) who studied the changes in the sodium and potassium concentrations in the blood and urine during exposure to high temperatures have published highly contradictory results with no data on correlations with changes in basal metabolism. Thus, Frada and Mentasana found a fall of the sodium level and rise of the potassium level in human blood plasma during a rise in temperature. By contrast, G. A. Lushnikova found a rise of sodium and fall of potassium in the blood plasma of dogs subjected to an ambient temperature of 43° for 4 hours. At the same time, the studies of A. Yu. Yunosov et al. on foundry workers exposed occupationally to 32-38° showed no alterations in whole blood samples. Mitkova and Raitcheva examined blacksmiths who had worked at 30-40° and found an increase in the urinary excretion of sodium and potassium. Michelet, who examined 4 Europeans who spent 8 months in the Sahara, found a sharp decrease in the sodium content of the urine during the hottest period.

In our study, 8 subjects were placed into a thermal chamber where they were subjected to a temperature of 34-35° and humidity of 80% continuously over a 6-day period. We found that the sodium content of the blood plasma increased regardless of its intake with food, while the potassium level was initially a direct function of the content of this electrolyte in the food, but declined by the end of the experiment. The changes found in the potassium and sodium levels in the erythrocytes, which are a good model for studying both the intracellular electrolyte metabolism /33
(Hrnciar et al.) and adaptation processes (T. Kemen' and M. Antal),

suggested a correlation between sodium and potassium metabolism in the erythrocytes and the level of energy consumption during the process of thermal adaptation. To fully establish the existence of such a correlation, however, it was necessary to obtain a more complete picture of sodium and potassium metabolism, taking into account the intake of the electrolytes into the body and their excretion in the sweat and urine.

For this purpose we further processed and refined the experimental data and obtained additional materials pertaining to a control group and concerning the excretion of sodium and potassium with the sweat[1] which enabled us to analyze the sodium and potassium balance in the organism. The experiment involved 11 men ranging in age from 20 to 24, 8 of whom (groups 1 and 2) were seated in a thermal chamber for a period of 6 days at 34-35° and 80% relative humidity. The men in the control group (group 3) were seated outside the chamber under comfortable microclimatic conditions (18-21° and 40-60% relative humidity). All groups were considered to be in a state of "physical rest."

Group 1 (6 subjects) received a subcaloric food ration (1840 kcal/day) deficient in sodium and potassium (0.5 and 1 g, respectively). Group 2 (2 subjects) received a high-caloric ration ($\sim$ 4000 kcal/day) with a normal content of sodium and potassium (5-7 and 3-5 g, respectively). Group 3 (3 subjects) were fed a subcaloric diet deficient in sodium and potassium, like group 1.

Each morning before the subjects were fed, blood samples were taken from the finger of each subject with a Francke spring lancet, and a 24-hour urine was collected each day. In addition, Dr. K.

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1. Data on the excretion of sodium and potassium with the sweat were furnished us by Dr. K. K. Sil'chenko, to whom we express our sincere thanks.

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K. Sil'chenko collected sweat samples by the method of Kuno: polyethylene bags were attached hermetically to the subject's arm after the latter had been washed clean with distilled water. The quantity of sweat secreted per 24 hours was calculated on the basis of weight loss and the quantity of water ingested. The sodium and potassium content of the plasma, erythrocytes, urine and sweat was determined by flame photometry. Finally, senior scientific coworker Z. K. Sulimo-Samuilo performed gaseous exchange measurements by the Douglas-Holden method.[2]

The data obtained in the experiment are given in Fig. 1 and 2.

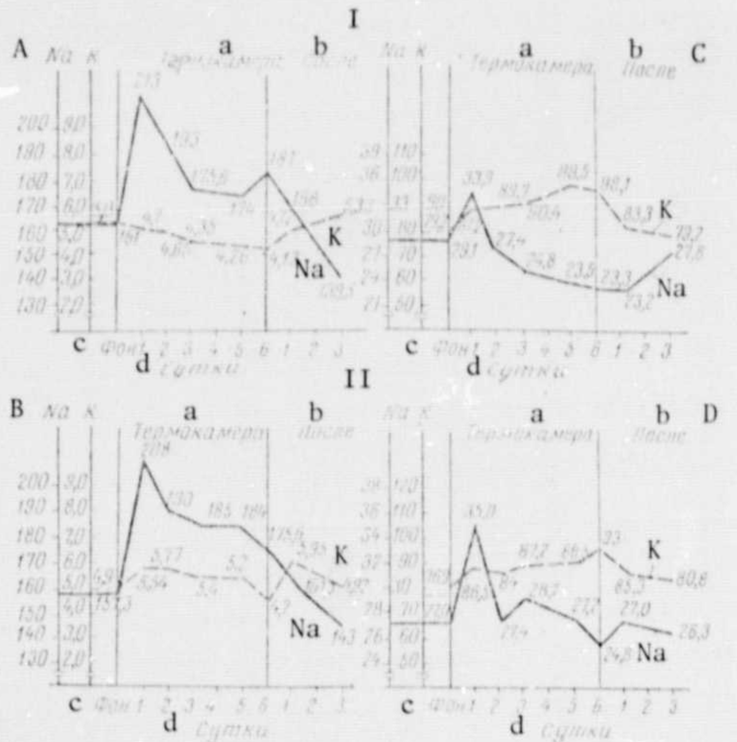

Fig. 1. Change in the sodium and potassium concentrations in the plasma and erythrocytes during adaptation to a high ambient temperature (in mEq/ℓ).

Key next page.

2. Energy consumption values based on gas exchange data were calculated by us.

Key to Fig. 1:

I - group 1 (subcaloric diet); II - group 2 (high-caloric diet); A,B - plasma; C,D - erythrocytes; Na - sodium; K - potassium; a - thermal chamber; b - after; c - baseline; d - days. Note: Commas in numerical data are equivalent to decimals.

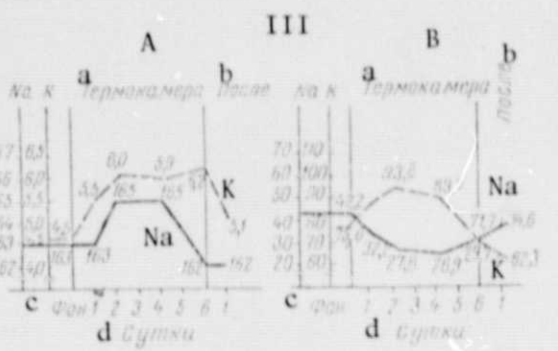

Fig. 2. Change in the sodium and potassium concentration in the plasma and erythrocytes in the control group (in mEq/ℓ).

III - group 3; A - plasma; B - erythrocytes; Na - sodium; K - potassium; a - thermal chamber; b - after; c - baseline; d - days.

Analysis of the data presented in Fig. 1 and 2 shows that the changes in the sodium and potassium concentrations in the blood plasma and erythrocytes of the subjects in group 3 (control) differ from the indices found for groups 1 and 2. For example, the increase in the sodium content of the blood plasma was insignificant compared with the plasma sodium of subjects in the thermal chamber (total increase of 2 mEq/ℓ in group 3 vs. average increase of 20 mEq/ℓ in groups 1 and 2 by the end of the experiment). The control group differed from group 1 and, in part, group 2 in that its plasma potassium level was elevated early on in the experiment. The change in the erythrocyte sodium level of group 3 was similar in tendency to the erythrocyte sodium changes recorded in the heat-exposed groups. However, the initial erythrocyte sodium level in group 3 was significantly higher than that of the first two groups (42.2 ± 1.9 mEq/ℓ in group 3, 27.0 ± 1.76 mEq/ℓ in group 2). As the experiment progressed, the erythrocyte sodium level in group 3 became approximately equal to the intial data in groups 1 and 2 on the 2nd, 3rd, 4th and 6th days. The erythrocyte potassium level of group 3 was elevated early on in the experiment. This was observed only in the first half of the experiment, however. By the 6th day the potassium concentration had fallen to /34

its initial value. In the heat-exposed subjects, on the other hand, the greatest increase in the erythrocyte potassium content was observed during the second half of the experiment.

It can thus be assumed that the change in the sodium and potassium content of the plasma and erythrocytes in groups 1 and 2 was caused chiefly by the action of a high ambient temperature. /35

On investigating the levels of energy consumption during the process of thermal adaptation in groups 1 and 2, we observed fairly significant differences (Fig. 3).

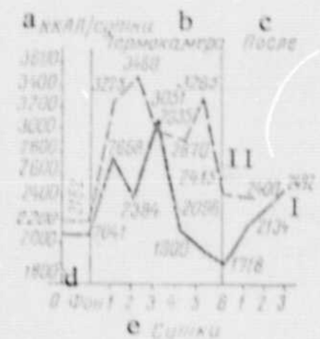

Fig. 3. Change in energy consumption on a sub- and high-caloric diet during adaptation to a high ambient temperature (in kcal/day).

I - group 1 (subcaloric diet); II - group 2 (high-caloric diet); a - kcal/day; b - thermal chamber; c - after; d - baseline; e - days.

As Fig. 3 shows, two phases are evident in the energy consumption level recorded for group 1. During the first 3 days of the experiment the energy consumption level rose from 2041 ± 15.5 to 2668 ± 302--3051 ± 218 kcal/day. It approached the initial level only on the 4th day (2096 ± 136.5 kcal/day). On the 5th and 6th days the energy consumption level was below the initial value (1900 ± 121.5 and 1718 ± 56.5 kcal/day). The energy consumption levels in groups 2 were high throughout the 6-day period. The average consumption for the first 5 days was 3000 kcal/day, reaching 3460 ± 170 kcal/day on the 2nd day. It was somewhat lower on day 6, when it approached the initial level (2415 ± 50 kcal/day compared with 2162 ± 17.5 kcal/day).

Corresponding to these differences in energy consumption levels in groups 1 and 2 are differences in the rise of rectal temperature, which is a highly accurate index of themal stress (G. Kh. Shakhbazyan). In the subjects of group 1, the rectal temperature was 37.1 to 37.2°, with variations of ±0.1°, throughout the course of the experiment. The rise of rectal temperature to 37.3-37.5 ± 0.2° in the subjects of group 2 indicates that a high-caloric diet heightens the effects of thermal stress. The degree of sweat secretion, which also serves as a criterion of thermal stress (G. Kh. Shakhbazyan), confirms the adverse effect of a high-caloric diet on the thermoregulatory system. Thus, the average daily sweat secretion was equal to 1.8-2.1ℓ in group 1, and 3.1-3.7ℓ in group 2. Some limitation of water consumption in group 1 may have played a certain role in this phenomenon.

A close correlation is observed between changes in energy consumption and the sodium and potassium metabolism. For example, we see in Fig. 1 and 3 that as the erythrocyte sodium in group 1 fell on days 5 and 6 from 29.1 ± 2.12 to 23.5 ± 1.34--23.3 ± 0.8 mEq/ℓ, the energy consumption also fell below the initial level. In group 2, the erythrocyte sodium content was below the initial value only on day 6 (24.8 ± 1.3 mEq/ℓ). On the same day, the energy consumption also declined and approached the initial level. The sodium content of the erythrocytes, meanwhile, attained a maximum in both groups.

The intracellular redistribution of sodium and potassium (see Fig. 1) that accompanied the decrease in energy consumption (see Fig. 3) is in direct relation to the excretion of both electrolytes from the body (Fig. 4).

We see in Fig. 4 that the excretion of sodium in the sweat and urine at a high ambient temperature considerably exceeds the loss of potassium. Analysis of the relationship between the intake and excretion of each electrolyte is of particular interest. Thus,

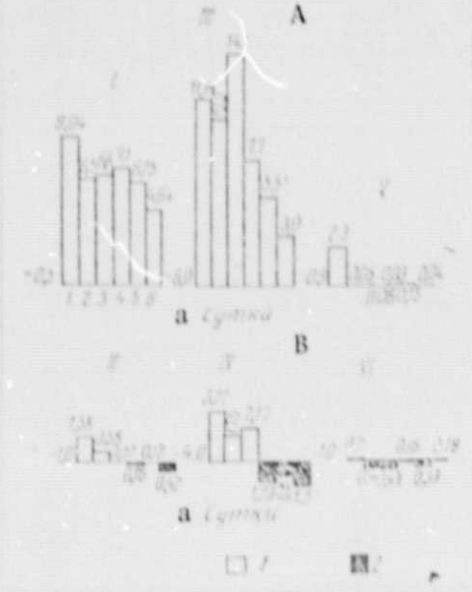

Fig. 4. Relative indices of daily sodium and potassium excretion (in g) in the 3 groups for given Na and K intakes [the intake of Na and K with the food is designated by a negative number (-0.5 and -0.6-1.0 and -4.0) at the bottom of the diagrams and is subtracted from the daily indices of their excretion].

Key: A - sodium; B - potassium; I-II - group 1; III-IV - group 2; V-VI - group 3. 1 - positive balance; 2 - negative balance; a - days.

if the subjects in group 1 received 0.5 g sodium/day with their food, the average daily excretion of this substance was approximately 7 g. The sodium losses over the 6-day period amounted to more than 40 g at a total intake of only 3 g with the food. In the subjects of group 3, who were not subjected to high temperatures and were fed a subcaloric diet, 2.8 g sodium were excreted on the 1st day. On subsequent days the intake of this electrolyte was equal to its excretion. A total of 3 g sodium was ingested with the food during the 6-day period, and 5 g was excreted, which is 8 times less than in group 1. The sodium losses in group 2, which received a normal quantity of sodium (5-7 g/day), were twice as great as in group 1, and amounted on the average to 14 g per day, or more than 80 g over the 6-day period. It should be noted that sodium excretion in /36 the sweat and urine was nonuniform in groups 1 and 2; by the 6th day it had declined by a factor of 2 to 3 in comparison with the 1st day. These data indicate a direct correlation between intracellular sodium and the intensity of metabolic processes, since the removal of 40 g sodium (≈ one-third of its reserves in the body) is accompanied by a decline in the level of energy consumption.

A quite different picture was observed with regard to the potassium balance. For example, while the losses of this electrolyte in group 1 amounted to about 2.5 g on day 1 and 1.5 g on day 2 (at an intake of 1 g/day), its intake exceeded its excretion from the 3rd day on (= negative balance). In group 2, the excretion of potassium was 1.5 times greater than its intake for the first 3 days, but fell below its intake from the 4th day on. In other words, a negative potassium balance was also observed in this group. The negative potassium balance accompanied by an increased erythrocyte potassium level in the subjects of group 2 and the fall of metabolsim are indicative not only of the interrelationship of these processes, but also of the subjects' demand for potassium ions. The potassium deficiency that arose in group 3 on the 2nd day of the experiment together with its increased concentration in the erythrocytes (see Fig. 2) suggests a certain decrease of the metabolic process associated with a subcaloric diet under conditions of physical rest.

Evidently the changes in sodium and potassium metabolism that occur during thermal adaptation are a direct correlate of the energy metabolism and are directed toward reducing the intensity of metabolic processes, i.e. can be regarded as adaptive phenomena.

Conclusions

1. Continuous exposure to a high ambient temperature leads initially to a significant rise in the level of energy consumption, apparently associated with the expenditure of surplus energy reserves.

2. The process of thermal adaptation is accompanied by a decline of the energy consumption level together with the transfer of potassium ions into the erythrocytes and the efflux of sodium ions from them, one-third (40 g) of which are excreted from the body in the sweat and urine.

3. The variation of the sodium and potassium concentrations in the erythrocytes may serve as an index of the state of adaptive processes under conditions of a high ambient temperature.

REFERENCES

1. Afanas'yev, B. G. and V. A. Zhestovskiy, Voyen.-med. zh. 7, 48 (1969).

2. Kemen', T. and M. Antal, in: Problemy biokhimicheskoy adaptatsii [Problems of Biochemical Adaptation], Moscow, 1966, p. 51.

3. Kuno, Ya., Perspiratsiya u cheloveka [Human Perspiration], Moselw, 1961.

4. Shabkhazyan, G. Kh., Gig. i san. 12, 80 (1968).

5. Yunusov, A. Yu. et al., Med. zh. Uzbekistana 3, 26 (1969).

6. Consolazio, W. V., A. Yu. Yunusov et al., Med. zh. Uzbekistana 3, 26 (1969).

7. Du Bois, E. F., J. Am. Med. Ass. 77, 5 (1952).

8. Henane, R., Rev. Cps. vet. Armee 7, 2 (1966).

9. Hrnciar, J., J. Guncaga, M. Hrnciarova et al., Cas. Lek. ces. 101, 907 (1962).

10. Frada, G. and G. Mentasana, Folia med. (1960).

11. Kemen', T. and M. Antal, in: Problemy biokhimicheskoy adaptatsii [Problems of Biochemical Adaptation], Moscow, 1966, p. 51.

12. Kuno, Ya., Perspiratsiya u cheloveka [Human Perspiration], Moscow, 1961.

13. Mitkova, N. and V. Raitcheva, Arch. Mal. prof. 25, 509 (1964).

14. Michelet, J., Ibid. 25, 127 (1964).